SONOMA WATER FUTURE RAINFALL DATABASE

Data User Guidance

Prepared for
Sonoma Water

Working Version: April 2024

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1. EXECUTIVE SUMMARY

Sonoma Water has developed a Future Rainfall Database to support planning and design of water treatment, water supply, and flood management projects for improved resilience to storms under a changing climate. The database was derived from downscaled climate model data and contains spatial data for projected 24-hour design storm estimates for a range of return periods, future time horizons, and greenhouse gas emissions scenarios. The database also includes projected changes in mean annual precipitation and time series of daily rainfall for multiple climate models at each downscaled climate model grid cell.

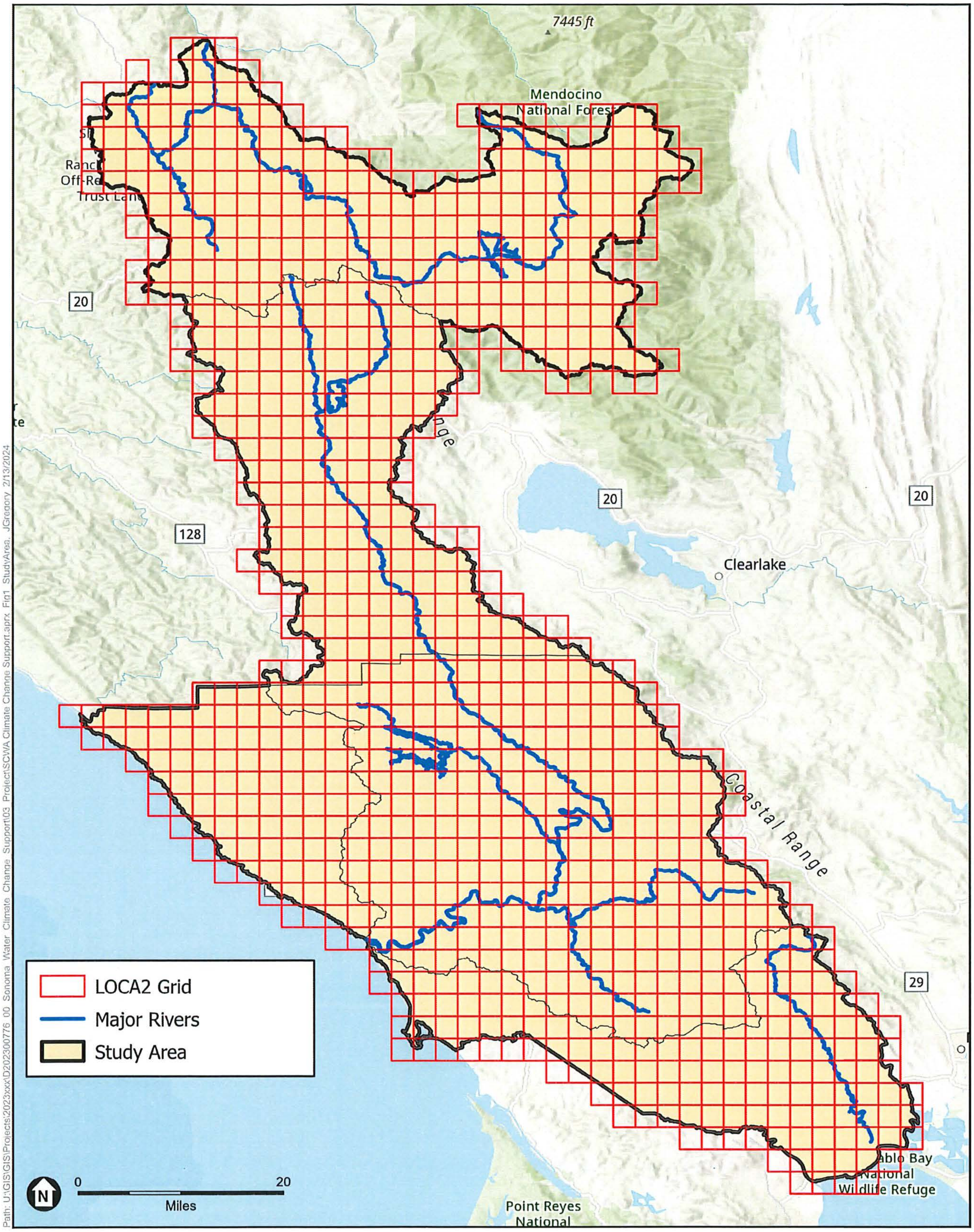
The database was developed using downscaled climate model output from the latest global climate models and emissions scenarios from the Intergovernmental Panel on Climate Change (IPCC): IPCC's Phase 6 Coupled Model Intercomparison Project (CMIP6, IPCC 2021). As shown in Figure 1, the data covers Sonoma County as well as the Russian River and upper Eel River watersheds at a 3km spatial resolution. Projected changes in 24-hour design storms were mapped onto National Oceanic and Atmospheric Administration (NOAA) Atlas 14 design rainfall rasters to derive 800m resolution rasters of future design rainfall.

The database can be used to quantify potential future changes in key metrics like the 100-year storm depth for flood protection projects. The data can support further analysis such as hydrologic and hydraulic models used by Sonoma Water for asset management and planning.

This User Guidance document outlines a process to guide Sonoma Water project teams in selecting appropriate future climate scenarios for analysis based on factors like asset exposure, vulnerability, criticality, and risk tolerance (Section 4). Worked examples are provided for two current projects - rehabilitation of the flood facilities that comprise the Central Sonoma Watershed Project and the updated Sewer System Evaluation Capacity Analysis for the Russian River County Sanitation District wastewater collection and treatment infrastructure (Section 5).

Working with climate projections requires grappling with significant uncertainty, particularly for extreme events in the late 21st century. This User Guidance report recommends use of the ensemble mean from multiple climate models, except for critical assets where consequences of failure are severe. For those projects, the impacts of upper-bound climate scenarios should also be evaluated.

As one of the first water agencies striving to consistently incorporate climate projections into asset planning, Sonoma Water expects to refine its approach over time. The database contents and this guidance document are an important first step toward climate-resilient decision making to protect public safety and infrastructure investments. Both are living documents and intended to be refined and updated as appropriate.



SOURCE: ESA, 2024

Sonoma Water Future Rainfall

Figure 1

Map of Study Area

2. BACKGROUND AND PURPOSE

In recognition of California's rapidly changing climate and at the direction of Sonoma Water's Energy and Climate Resiliency Policy (2023) and Climate Adaptation Plan (Sonoma Water, 2021), Sonoma Water has committed to incorporating future climate data into studies, planning, design, and construction projects implemented by Sonoma Water to the extent feasible and relevant. In support of this commitment, Sonoma Water invested in a Future Rainfall Database of 24-hour design storms to guide rigorous planning for resilience to event-based storms under a range of possible climate futures.

Climate adaptation requires decision-making under uncertainty. As a regional water wholesaler, flood management agency, and manager of eight sanitation districts and zones, Sonoma Water's decisions have a significant impact on the health and safety of the community. This User Guidance Document is a resource to support Sonoma Water project teams in appropriately incorporating future climate data when planning and designing projects vulnerable to future changes in rainfall. This resource is meant to guide staff through an assessment of asset exposure, vulnerability, and criticality to select an appropriate future climate rainfall scenario. The selected scenario would then be applied via project-specific analyses to inform project decision-making. Maintenance and capital investment decisions always require careful evaluation of multiple criteria, including risk, cost, and level of service. The process outlined herein establishes a process by which future climate data are rigorously and consistently considered in support of that decision-making.

Sonoma Water is embarking on a new effort to consistently incorporate climate projections into its infrastructure planning and capital projects. Few water agencies in the United States are consistently utilizing future climate data to guide their decisions in stormwater and wastewater resilience planning (Finzi Hart, 2022). As such, it is expected that Sonoma Water's approach will be refined over time through experience and broader advancements in climate downscaling methods and adaptation science.

Though this document may be useful as a resource to other agencies and entities grappling with climate adaptation, its recommendations are specific to Sonoma Water's decision-making context and risk tolerance and may not be appropriate in other contexts. This report is a living document and intended to be refined and updated as appropriate.

2.1 Future rainfall database

Sonoma Water has developed a database of future rainfall estimates to support understanding, planning for, and addressing future climate impacts. The database contains spatial and time-series data reflecting estimates of projected rainfall for a range of time horizons and climate scenarios. The data, methods, results, and assumptions used to develop the database are documented in a separate report (ESA, 2024).

2.2 Climate background and terminology

The climate data used to populate the database are derived from climate modeling conducted as part of the sixth assessment report from the International Panel on Climate Change (IPCC, 2021). This section summarizes some of the key terms and concepts used by the International Panel on Climate Change (IPCC) and how they relate to the future climate database.

General Circulation Models (GCMs) – As part of the IPCC's Phase 6 Coupled Model Intercomparison Project (CMIP6, IPCC 2021) multiple research groups have developed GCMs to simulate atmospheric and oceanographic climate processes on a global scale. The GCMs are run according to standardized scenarios developed by the IPCC to represent future socioeconomic conditions and greenhouse gas emissions scenarios:

- **Shared Socioeconomic Pathways (SSPs)** – The SSPs are the socioeconomic scenarios developed by the IPCC to represent a range of plausible future conditions. Each SSP includes different assumptions for key variables including population, economic growth, education, urbanization, and the rate of technological development.

- **Representative Concentration Pathways (RCPs)** – The RCPs are the corresponding emissions scenarios developed by the IPCC to reflect different pathways for greenhouse gas emissions and other radiative forcings. Each RCP is named for the increase in radiative energy (in W/m^2) on the earth's surface over the 21st century.

Given the uncertainty in projecting future socioeconomic conditions and GHG emissions, it is best practice to include model results for multiple future scenarios to capture a range of projected outcomes. The future rainfall database is derived from GCM results for the following two SSP-RCP scenarios, which were selected for their alignment with Sonoma Water's Climate Adaptation Plan (CAP) (Sonoma Water, 2021), as well as guidance documents from California Department of Water Resources' Climate Action Plan and California's statewide climate assessments:

- **SSP2-4.5**, a medium-high pathway, assumes moderate socioeconomic challenges to mitigation and adaptation. RCP4.5 assumes that future earth-surface radiative energy increases by 4.5 W/m^2 between 2000 and 2100. It's a "middle-of-the-road" scenario, where trends do not shift markedly from historical patterns, making it a useful reference for assessing moderate climate responses.

- **SSP5-8.5**, represents a high greenhouse gas emissions trajectory, resulting in high challenges to mitigation butlow challenges to adaptation due to rapid economic growth, investments in human capital, effective institutions, and faith in the ability to manage environmental challenges through technology and engineering solutions. RCP8.5 assumes unmitigated emissions resulting in a future radiative energy increase of 8.5 W/m^2. This scenario represents a future condition with unmitigated emissions, serving as a 'worst-case' reference.

Future Periods – The future rainfall database includes GCM results for the midpoint of three future periods, which were selected in alignment with the CAP:

- Early century: 2015-2045, (midpoint – 2030);
- Mid-century: 2046-2075, (midpoint - 2060); and
- Late century: 2070-2100, (midpoint – 2085).

Downscaling – Downscaling is the process by which the spatial resolution of GCM output is increased, making it more suitable for local and regional applications. A key downscaled dataset for California is the 'locally constructed analogs' (LOCA) product developed at the Scripps Institute of Oceanography (Pierce *et. al.* 2015). A recent update to LOCA, released in May 2023 (Pierce *et. al.* 2023), applied the most current methodology and increased the spatial resolution to 3-kilometer (km) square cells for a California-specific domain (California LOCA2). The California LOCA2 dataset contains daily temperature and rainfall from 1950-2100 for 15 GCMs that were found to best replicate California climate patterns (Krantz *et. al.* 2021). The 15 models produce rainfall data for a historic period (1950-2014) used to train the models against observed data for this period, and a projected future period (2015-2100) representing estimated rainfall under future climate scenarios. Of this 15-model ensemble, only 13 models from the California LOCA2 dataset contained output for the two emission scenarios selected for the rainfall database.

Ensemble statistics – The ensemble of results from the 15 downscaled climate models represents a plausible range of projected future climate conditions under each emissions scenario and each future period. The future rainfall database includes the ensemble mean for each scenario, as well as the mean plus one and two standard deviations (mean+1SD and mean+2SD). An example of the model distribution with mean and standard deviation statistics is shown in **Figure 2**. This figure shows the distribution of the percent change in late century 100-year rainfall for a single grid cell located over the Mirabel & Wohler water supply collector wells on the Russian River.

Climate driver – This term is used to describe key variables that will drive impacts in each system. For example, the future 100-year rainfall depth is a key climate driver for flood analysis since changes in the amount and rate of rainfall directly impact watershed processes and flooding that may impact infrastructure. The future rainfall database includes several key hydrologic climate drivers (summarized in Table 1) that can support analysis of climate risk and vulnerability.

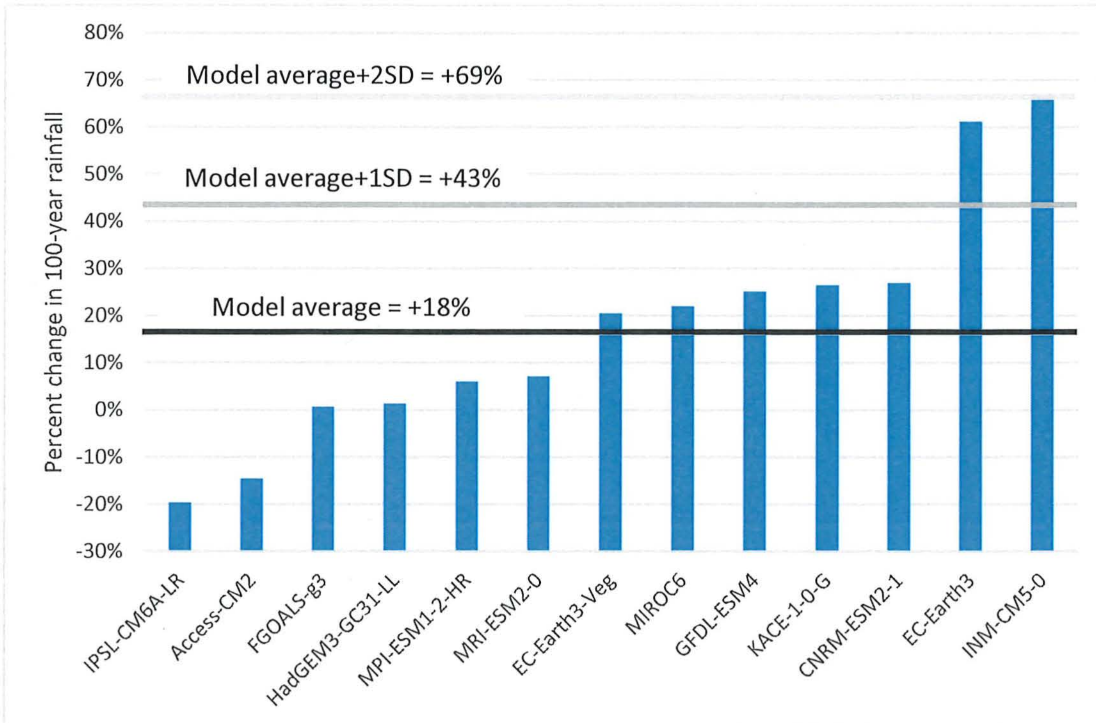


Figure 2. Model distribution and statistics for percent change in Late Century 100-year rainfall at downscaled climate grid cell over the Mirabel & Wohler Collectors

3. DATABASE OVERVIEW

Sonoma Water retained ESA to develop a future rainfall database containing time series and geospatial data for a domain covering all of Sonoma County as well as the Russian River and Upper Eel River watersheds as shown in Figure 1. California LOCA2 data were processed by ESA to produce a database of estimated design rainfall for three future periods (early century [2015-2045, 2030 midpoint], mid-century [2046-2075, 2060 midpoint], and late century [2070-2100, 2085 midpoint]) and two emission scenarios (medium-high [SSP2-4.5], and high [SSP5-8.5]). The database contains the following data:

- **Daily rainfall time series** (Excel format) – Daily data were extracted for each California LOCA2 grid cell in the study domain (928 total). The data are stored in individual excel files for each of 13 downscaled climate models. Each model grid cell has a unique Climate ID which can be spatially located using the shapefile[1] with the database. Each column in the excel files contains the data for a single grid cell with the Climate ID for each cell as the column header.
- **Future climate scalars** (raster format) – The LOCA2 daily data were used to develop gridded scalars representing percent change for each future period relative to the historic period for mean annual precipitation (MAP) and 24-hour design rainfall for a variety of return periods. The database contains rasters for MAP scalars (3km) and design depth scalars (3km) for each of the three future periods and two emissions scenarios for each climate model. Raster scalars include the model mean, mean+1SD and mean+2SD.
- **Design rainfall depth (24-hour)** (raster format) – The 24-hour design rainfall scalars were applied to the National Oceanic and Atmospheric Administration (NOAA) Atlas 14 spatial depth-duration-frequency dataset (800m resolution) to produce rasters of future design rainfall depths for a 24-hour storm with 1-, 2-, 5-, 10-, 25-, 50-, 100-, and 500-year return periods. Again, rasters include the model mean, mean+1SD and mean+2SD.

[1] LOCA2_Grids_SonomaFutureRainfallScenarios.shp

A summary of the data files contained in the database is provided in Table 1.

TABLE 1. FUTURE RAINFALL DATABASE CONTENTS

Data type	Time Period	Emissions scenario	Variable	Climate model ensemble statistic
Geospatial Rasters (3km square scalars, 800m design depths)	Early century (2016-2045 basis, 2030 midpoint)	Medium-high (SSP2-4.5) High (SSP5-8.5)	24-hour depth for 1-, 2-, 5-, 10-, 25-, 50-, 100-, and 500-year return periods* Mean Annual Precipitation	Mean Mean + 1SD Mean + 2SD
	Mid century (2046-2075 basis, 2060 midpoint)	Medium-high (SSP2-4.5) High (SSP5-8.5)	24-hour depth for 1-, 2-, 5-, 10-, 25-, 50-, 100-, and 500-year return periods Mean Annual Precipitation	Mean Mean + 1SD Mean + 2SD
	Late century (2070-2099 basis, 2085 midpoint)	Medium-high (SSP2-4.5) High (SSP5-8.5)	24-hour depth for 1-, 2-, 5-, 10-, 25-, 50-, 100-, and 500-year return periods Mean Annual Precipitation	Mean Mean + 1SD Mean + 2SD
Excel files	1950-2100 Daily data	Medium-high (SSP2-4.5) High (SSP5-8.5)	Daily rainfall data (inches)	13 individual models Model mean Mean + 1SD Mean + 2SD Max Min

*Scalar rasters at 3km resolution and raw design depth rasters at 800m resolution provided for all return periods.

The database can be used to characterize future hydrology for a broad range of water resource, flood control, and sanitation system applications that rely on design event-based simulation or analysis. Some example applications include:

- **Flood risk** – The 100-year storm is one of the most common standards applied for evaluating flood risk in the United States. Using the design depth rasters, analysts can quantify 24-hour, 100-year design rainfall depth for one or more future periods under an appropriate emissions scenario. The rasters can be used to quantify spatially varying design rainfall depth for larger watersheds and multiple subwatersheds. Future design rainfall can be used as input to hydrologic models to simulate future runoff scenarios and combined with hydraulic models to simulate future flood risk and damage to infrastructure.

- **Water supply** – The daily rainfall time series data can be used as input to hydrologic models used for evaluating water supply. Additional data such as temperature may be needed to conduct this analysis.

- **Wastewater collection and treatment** – Future rainfall data can be used to evaluate a range of potential impacts to wastewater systems. Higher peak flows could stress unit treatment processes and require evaluation of potential capacity upgrades. Additionally, changes in dry weather patterns may impact irrigation demands for treated effluent reuse applications. The future rainfall data can be used in hydraulic models of the collection system and water balance analyses for treatment plant capacities to assess these potential impacts.

Though outside of Sonoma Water's jurisdiction, the Future Rainfall Database could be critically useful to Cities and other entities designing infrastructure to withstand future climate conditions. One example is storm drain master planning:

- **Storm drain master planning** – Storm drains are typically designed to handle smaller more frequent floods such as the 10- or 25-year event. The depth rasters for the 24-hour storm can be applied to hydrologic and hydraulic models to quantify future rainfall-runoff scenarios and guide capital improvement planning for future upgrades to a given city's storm drain system.

4. SCENARIO SELECTION

The future rainfall database contains daily time series data from 1950-2100 and design rainfall[2] for early, mid, and late century under medium-high and high-emissions scenarios and a range of ensemble statistics[3]. The data can be used to evaluate the range in anticipated degree of change, as well as direct input to analytical tools including hydrologic and hydraulic models. The process outlined herein for selecting an appropriate scenario for analyzing and planning for future climate impacts draws from a literature review of industry best practice as well as the preliminary framework developed for Sonoma Water's Climate Adaptation Plan (Sonoma Water, 2021). A flowchart diagramming the scenario selection process is provided in Figure 3, and this section provides more detail to guide scenario selection. Section 5 shows two worked examples based on Sonoma Water projects that are currently in development.

The scenario selection process begins by scoping the problem to evaluate the need for climate-specific analysis. This involves characterizing what system, asset, or activity stands to be impacted by the proposed project, climate drivers and anticipated changes to those drivers, and the relevant time horizon for assessing changes and impact. Following this scoping process, an evaluation of the climate risk inherent to the proposed project should be conducted, reflecting the combination of exposure (amount of change) and vulnerability (tolerance to the change). Projects with low vulnerability or exposure may not require additional climate-based analyses. As a final step, the risk assessment should be augmented by a consideration of asset criticality.

Sonoma Water recognizes that the database and recommended analyses herein will be unfamiliar to many skilled project managers. Additionally, much of the subsequent decision-making process is subjective in nature and will require consultation and coordination within the project team, Sonoma Water's Climate Resiliency Group, and Sonoma Water leadership. Sonoma Water's Climate Resiliency Group is committed to providing both ongoing training to staff as well as technical assistance to those team members who may find themselves grappling with a complex analysis reliant upon uncertain data.

[2] 1-, 2-, 5-, 10-, 25-, 50-, 100-, and 500-year return periods

[3] Model mean, mean+1SD, mean+2SD

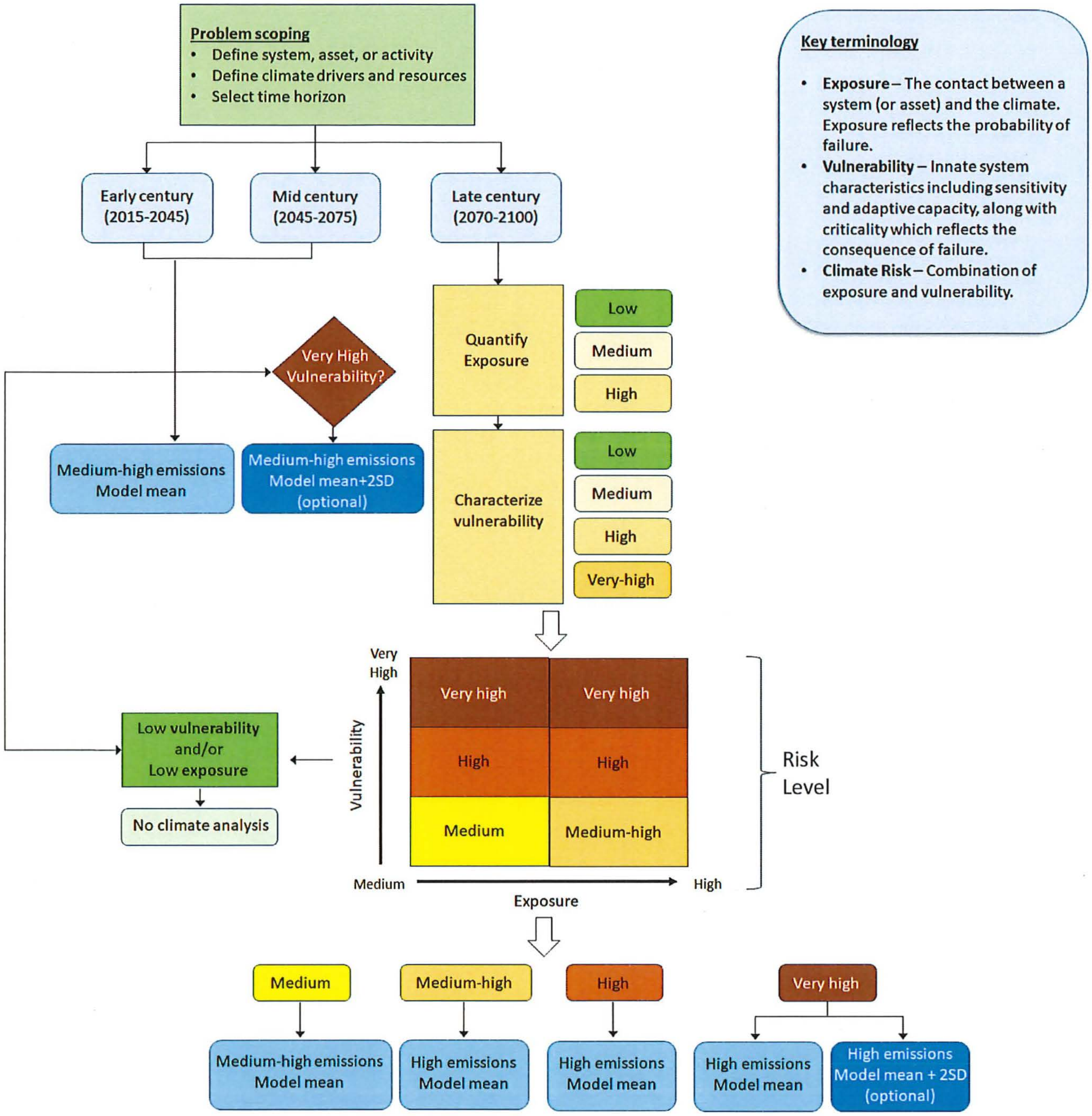


Figure 3. Sonoma Water climate scenario selection process

4.1 Problem scoping

As part of scoping the problem the following elements should be identified:

- **System, asset, or activity** – The need for climate analysis and the type of analysis that could inform management decisions will depend on the details and risks for a given system, asset, or activity. The boundaries (i.e. jurisdictional, watershed) of the analysis should be identified at this stage.

- **Time horizon** – Given the non-stationarity of climate change, future time horizons are represented by three periods: (1) Early century (2015-2045), (2) Mid-century (2045-2075), and (3) Late century (2070-2100). The scoping process should identify the relevant time period for the project or system under consideration. Considerations may include the design life of a given facility, general plan time horizons, time limits for a given permit, etc. In projects seeking to incorporate adaptive management (e.g. phased adaptation measures implemented over time), it may be appropriate to select multiple time horizons for study.

- **Climate drivers and resources** – Because this database is designed to meet the needs of flood- and water supply-based risk analyses, the assumed project driver is rainfall. However, in some cases, additional climate drivers may be relevant for consideration. Sonoma Water's Climate Resiliency team is available to provide support to project managers seeking to identify and procure data on additional project climate drivers.

Once the problem has been scoped, the next steps in scenario selection involve defining exposure, sensitivity, and criticality.

4.2 Exposure

Once the climate drivers have been identified, data sources, including the future rainfall database, can be used to quantify asset exposure over the relevant time horizon. Exposure can be defined as the contact between a system (or asset) and the climate (e.g. assets in the floodplain have a high degree of exposure). Additionally, exposure is one dimension of probability of failure from climate change impacts over the asset's lifetime. Assets with higher exposure have an increased probability that climate change will negatively affect or cause failure of the asset. For early- and mid-century applications, the medium-high emissions scenario (SSP2-4.5) should be used for Sonoma Water facilities. For these periods, the two emissions scenarios show significant overlap, with SSP2-4.5 generally higher and thus more conservative. For the late century horizon, both emissions scenarios should be evaluated to characterize the estimated potential range of exposure (e.g. run both scenarios through any hydrologic and hydraulic models to assess the range of possible flood exposure). Exposure should be characterized as medium or high based on professional judgment and evaluation of these preliminary studies. Low exposure would imply little or no contact between the system and the climate and would indicate that the project team could deprioritize any further analysis of climate impacts. This preliminary estimation of the range of exposure provides essential insight for the subsequent evaluations of Vulnerability (4.3) and Climate Risk (4.4).

4.3 Vulnerability

Vulnerability integrates concepts of sensitivity, adaptive capacity, and criticality. Sensitivity refers to the innate characteristics of a given system, asset, or activity which determine the impact of exposure to a given climate driver (e.g. does the asset contain any below-ground electrical components, or are those assets elevated above any potential floodwaters?). Sensitivity evaluation should consider the severity of any potential impacts given the amount of exposure assessed in Section 4.2. Adaptive capacity refers to the ability of a system or asset to respond to changing conditions, thereby avoiding or mitigating impacts. Criticality could include a range of considerations reflecting consequence of failure, including the potential impact of the loss or failure of a system to public health, safety, environment, and economic stability, as well as replacement costs and degree of redundancy. For vulnerable critical projects, an extreme-high-risk scenario should be added to the scenarios under evaluation. The extreme-high-risk scenario is two standard deviations above the model mean for the highest emissions scenario. Given the uncertainty in future climate projections, and the fact that several validated models show projected changes above the mean, this scenario will provide a valuable upper bound condition to inform planning, mitigation, and adaptation efforts.

Vulnerability should be characterized as medium, high, or very high based on professional judgment, considering sensitivity, adaptive capacity, and criticality. Low vulnerability would imply little, or no impact caused by climate change and would indicate that the project team could deprioritize any further analysis of climate impacts.

4.4 Climate Risk

Risk refers to the combination of exposure and vulnerability. For the framework presented in this document, there are six combinations of exposure (medium and high) and vulnerability (medium, high, and very high) for which analysis of future climate impacts are recommended, as shown in Figure 3. These risk combinations can be used to guide scenario selection. The lower emissions scenario mean (SSP2-4.5) should be selected for a risk combination of medium exposure and medium vulnerability. The higher emissions scenario mean should be selected if the study identifies a high degree of vulnerability, high degree of exposure, or both. If the study identifies very high system vulnerability (typically driven by high criticality), the project should utilize both the higher emissions scenario mean and the high emissions scenario mean + 2SD (see Section 4.5).

4.5 Other Constraints

Within each project context, a host of additional constraints and considerations may be relevant to consider. This document provides high-level guidance for scenario selection in project planning and analysis but recognizes that final decision-making on project design will require an evaluation of competing interests such as cost, physical constraints, environmental impact, and community support.

5. WORKED EXAMPLES

5.1 Central Sonoma Watershed Project (CSWP)

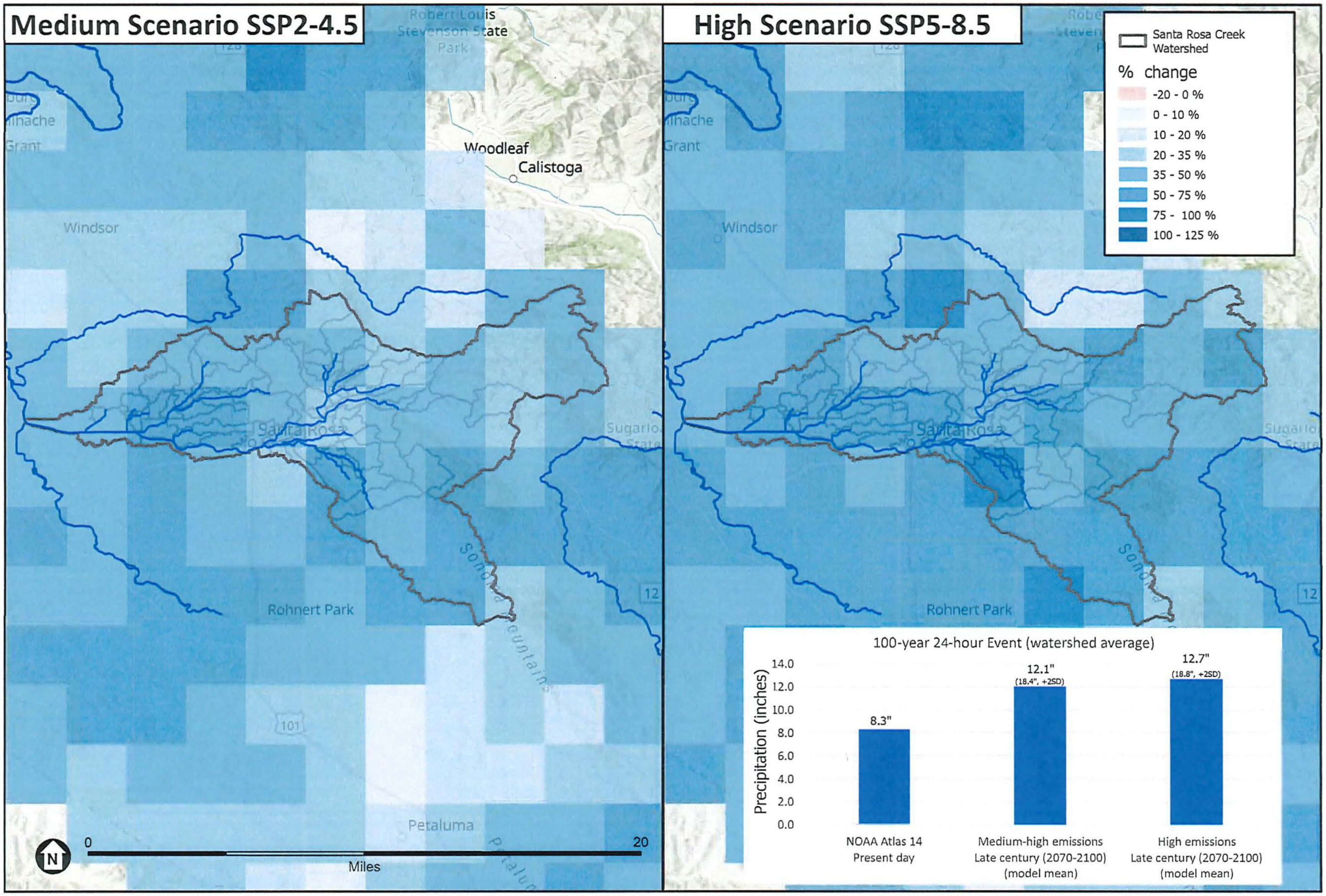
The Central Sonoma Watershed Project (CSWP), developed in 1958 by the Sonoma County Flood Control and Water Conservation District (now Sonoma Water), Santa Rosa Soil Conservation District (now Sonoma Resource Conservation District), and the USDA Soil Conservation Service (now Natural Resources Conservation Service (NRCS)), provides flood protection in the Santa Rosa Creek watershed through an integrated system of channels, culverts, bridges, conduits, reservoirs, outfalls, and diversion structures. The CSWP has exceeded its 50-year design life, and the Project is currently undergoing vulnerability assessment to ensure reliable future flood mitigation for the City of Santa Rosa, given changes in development, population growth, seismic risk, and both past and future climate change. Sonoma Water is currently seeking technical assistance from NRCS to identify alternatives that could rehabilitate flood protection facilities and improve flood protection over the next 50 years. The future rainfall database and scenario selection process can be applied to the CSWP project following the flowchart in Figure 3 to evaluate future climate conditions.

Step 1: Scope the problem.

- **System, asset, or activity** – Flood protection infrastructure that comprises the CSWP. The particular focus for this evaluation will be the Santa Rosa Creek watershed.
- **Climate drivers and resources** – Rainfall and flow for extreme events. The 100-year discharge is one key design flow under evaluation for the CSWP. A coupled hydrologic-hydraulic model has been developed for Santa Rosa Creek and is the basis for defining design discharges. Data for late century 100-year rainfall from the future rainfall database can be input directly into the model of the system to estimate late century 100-year discharge.
- **Time horizon** – Late Future. The proposed design life of the upgraded CSWP is 50-years. Assuming construction is 5-10 years in the future, the appropriate analysis period for this project is Late Century (2070 – 2100).

Step 2: Quantify exposure.

The rasters for medium-high and high emissions for late century 100-year 24-hour rainfall can be used to develop inputs to the hydrologic model of the system. A map of the gridded scalars for this event is shown in Figure 4. These products were derived from the Database. As this figure shows, Late Century 100-year 24-hour rainfall shows a range of projected increases from 45% (medium-high emissions SSP2-4.5) to 52% (high emissions SSP5-8.5). The upper end of the model distribution (+2SD) shows an increase of 127%. These increases in rainfall are significant but will need to be incorporated into hydrologic models to evaluate the corresponding impact on flood risk before selecting an exposure rating. For this Worked Example exercise, the project is anticipated to incur High Exposure. For greater rigor, the two scenarios should be brought into CSWP's hydrologic model before assigning exposure.



SOURCE: ESA, 2024

Sonoma Water Future Rainfall

Figure 4
Santa Rosa Creek Watershed % change for late century 100-year rainfall (model mean)

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Step 3: Characterize vulnerability.

Prior analysis has found that facilities in the CSWP are highly sensitive to anticipated changes in future rainfall and hydrology. As currently designed and operated, the facilities have little to no adaptive capacity. Additionally, the CSWP provides critical flood protection for the City of Santa Rosa and surrounding areas. Impacts from future climate change range from more frequent and more extensive flooding to major events which could threaten public safety. Given the magnitude of adverse consequences if the system were to fail (high Consequence of Failure), key facilities within the CSWP including the Matanzas Reservoir dam and Spring Lake dams are highly critical.

Thus, for the purposes of this Worked Example, the current system has been rated with Very High Vulnerability.

Step 4: Combine exposure and vulnerability to characterize Risk.

The project was assigned an exposure rating of high and a vulnerability rating of very high. The combination of these factors represents risk. Thus, for this analysis, the system is rated as having Very High Risk.

Step 5: Select climate scenarios.

Given the exposure and vulnerability assessments, two scenarios are recommended:

1. Late century, high emissions (SSP5-8.5), model mean – This scenario provides projections on the higher end of the anticipated range of future extreme precipitation change appropriate for high-risk applications. For this example case, this could be a primary scenario considered for CSWP upgrades, taken alongside political, financial, and physical constraints.

2. Late century, high emissions (SSP5-8.5), model mean + 2SD – The very high vulnerability designation could warrant supplementing the primary scenario with this extreme high-risk scenario. This supplementary scenario will enable evaluation of the upper end of all model projections to understand system sensitivity to hydrologic inputs and consider an extra margin of safety appropriate to the consequences of system failure. This scenario should only be used when considering a critical system with the potential for severe impacts.

The completed flowchart for the CSWP example is shown in Figure 5. Selected scenarios from the future rainfall database can be used as input to the hydrologic-hydraulic model of Santa Rosa Creek to estimate future flows and flood extents. As shown in Figure 4, future 100-year rainfall increases from 8.3 to 12.7 inches and to 18.8 inches at the upper end of the climate model distribution. As noted above, the CSWP Worked Example is provided as an example of technical considerations for scenario selection for educational purposes in this report, but final decisions regarding infrastructure design may consider additional constraints.

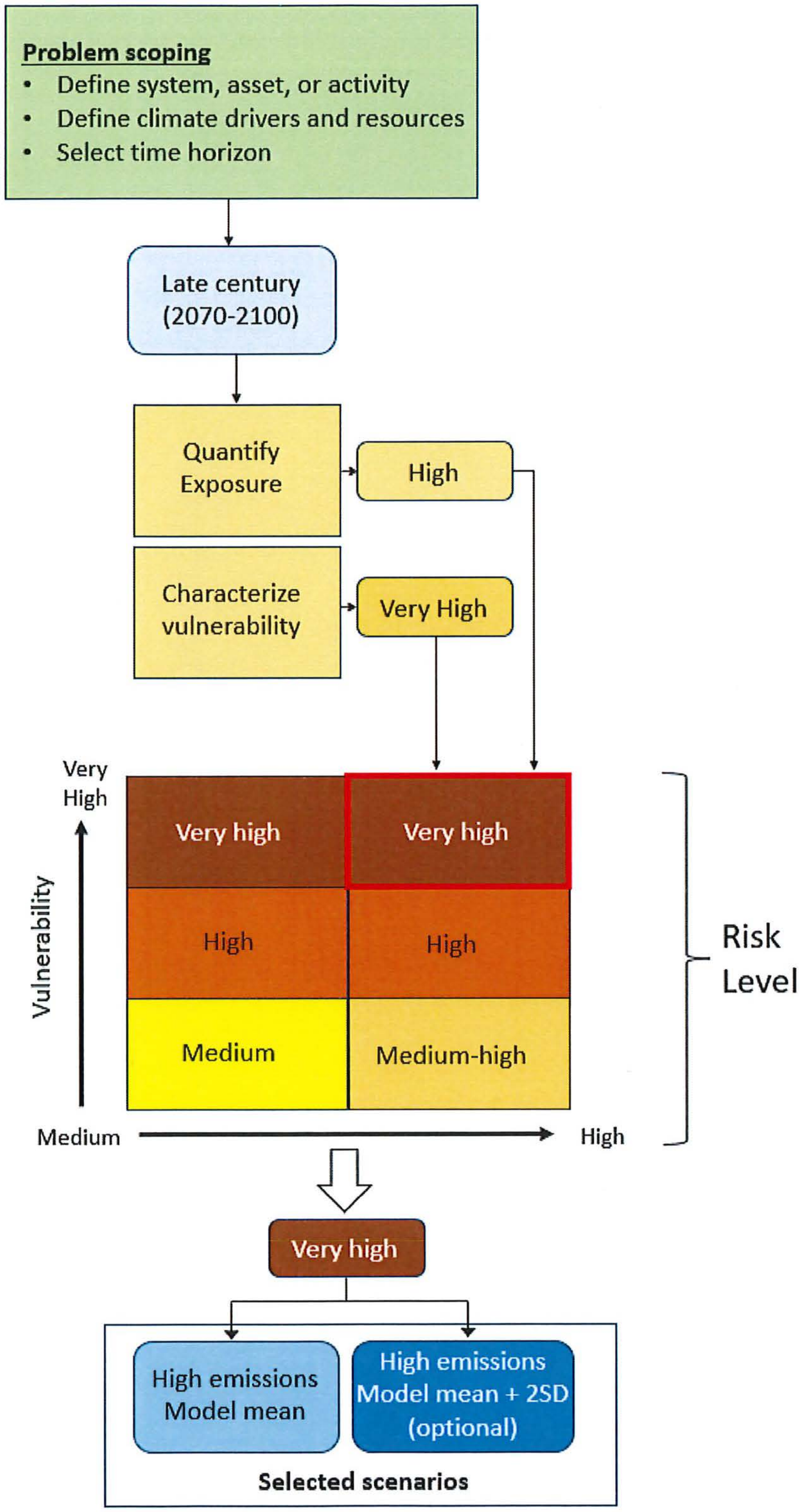


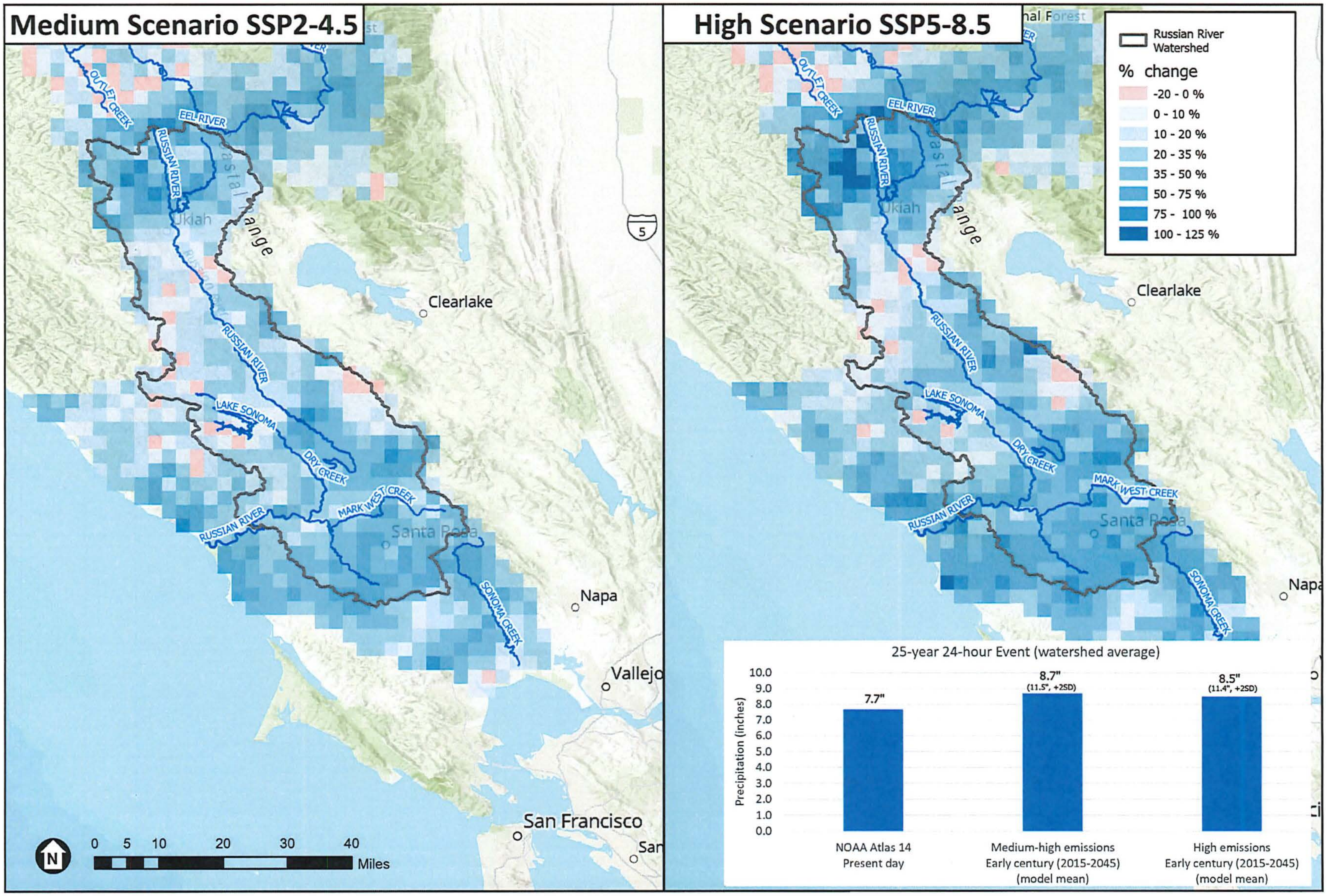
Figure 5. Completed climate scenario selection flowchart for Central Sonoma Watershed Project example

5.2 Russian River County Sanitation District (RRCSD) Sewer System Evaluation Capacity Analysis (SECAP) Plan Update

The RRCSD requires a revised SECAP to comply with Order R1-2021-0002 issued by the North Coast Regional Water Quality Control Board. The revised SECAP will include an engineering evaluation and a plan to correct identified capacity deficiencies in the collection system and treatment plant, including engineering and contingency measures to prevent, reduce, and mitigate spills. Additionally, the revised SECAP will identify potential capital improvements projects to eliminate, reduce, and mitigate overflow events.

Step 1: Scope the problem.

- **System, asset, or activity** – The RRCSD collection system and treatment plant.
- **Time horizon** – Early-future. Given that the timeline of the SECAP permit will need to be updated every ten years, design and impacts should evaluate near-term changes in climate drivers. Given the early-future time scenario, the analyst should select the medium-high emissions scenario (SSP2-4.5) for further analysis. A comparison of projected changes for both emissions scenarios at this time horizon for the 25-year event (see Climate Drivers) is shown in Figure 6. As this figure shows, Late Century 25-year 24-hour rainfall shows a maximum increase of 1-inch (+13%, medium-high model mean scenario [+49% at mean+2SD]).
- **Climate drivers and resources** – Rainfall and flow for extreme events. The permit update is currently considering two recent historic storms — an event that occurred on January 11-12, 2017, and an event that occurred on February 26-27, 2019 — which caused impacts to the system. The approximate return period for these events is 15-20-years. Design events of this magnitude drive disruption of treatment plant unit processes and sewer system overflows from Russian River backwater.



SOURCE: ESA, 2024

Sonoma Water River and Stream Channel Assessment

Figure 6
Russian River watershed % change for late century 25-year rainfall (model mean)

ESA

Step 2: Characterize vulnerability.

The updated SECAP will address near-term impacts to the RRCSD. Given anticipated changes to the climate, the RRCSD has moderate sensitivity. Impacts are expected to include: larger SSO extent for events on the order of a 25-year return period; as well as higher loading to the plant, which may disrupt treatment processes. High criticality consequences, such as plant failure, are not likely in this context. The WWTP and collection system has low adaptive capacity as it currently experiences substantial flooding risk due to high river stage, low lying developments, high infiltration, and inflow (I/I), road access, and power outages. Given these considerations in the context of the SECAP, for the purposes of this Worked Example, this project has been rated Medium Vulnerability.

Step 3: Select climate scenarios.

Given the vulnerability assessment, one scenario is recommended for this Worked Example:

1. Early century, medium-high emissions (SSP2-4.5), model mean – This scenario provides an estimate of future extreme precipitation change appropriate for analyzing impacts to this system. For this example case, this could be a primary scenario considered for RRCSD upgrades, taken alongside political, financial, and physical constraints.

The completed flowchart for the CSWP example is shown in Figure 7. Selected scenarios from the future rainfall database can be used as input to modeling or other technical analysis to characterize flows for the RRCSD system. As noted above, the SECAP Worked Example is provided as an example of technical considerations for scenario selection, but final decisions regarding infrastructure design will consider other constraints.

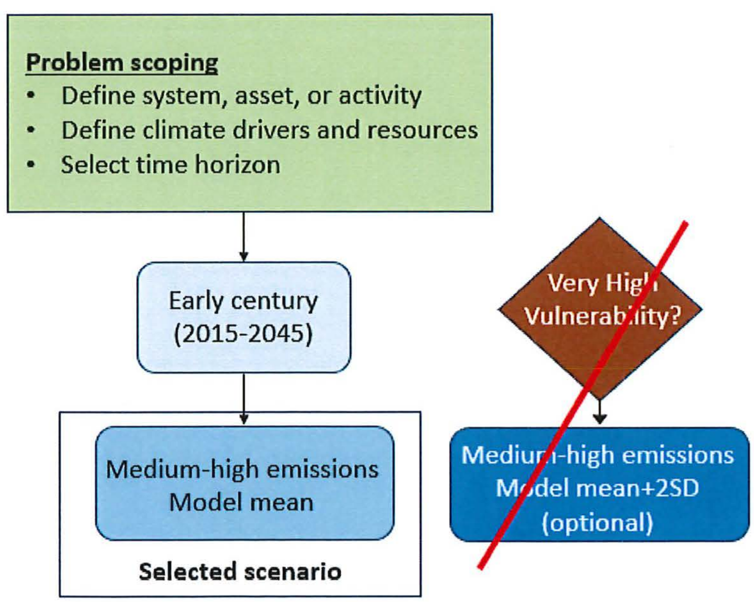


Figure 7. Completed climate scenario selection flowchart for RRCSD SECAP example

6. FURTHER CONSIDERATIONS

6.1 Adaptation and mitigation

This User Guidance Document is a resource to support Sonoma Water staff in appropriately incorporating future event-based climate data when planning for and designing projects and facilities. As identified in the Sonoma Water CAP, characterizing risk, vulnerability, and impacts of climate scenarios can support evaluating alternatives to mitigate or adapt to the impacts. The CAP includes recommendations for developing adaptation strategies, including specific strategies for Sonoma Water's management areas, and provides a framework to translate vulnerabilities into portfolios of concepts and integrated strategies to improve climate resilience.

Selection of an appropriate climate scenario to incorporate into risk and vulnerability analyses is an essential step in building climate resilient infrastructure. However, maintenance and capital investment decisions always require careful consideration of multiple criteria, including:

- Cost-Benefit Analysis: Potential adaptation measures must be evaluated against their costs and potential benefits/risk reduction. Life-cycle cost analyses can help determine if the benefits of a climate-resilient design outweigh the additional upfront capital expenditures.

- Physical/Technical Constraints: Available space, existing infrastructure, environmental impacts, and engineering limitations may restrict the potential suite of adaptation options that can be implemented for a given asset.

- Community/Partner Input: Implementing significant infrastructure changes always requires public engagement to better understand the needs of key partners and impacted communities, particularly the unique challenges faced by historically marginalized communities who may face compounding vulnerabilities.

For some cases, water management systems can incorporate resilience upgrades to address potential climate change impacts during general or master planning cycles. However, in some cases, analysis may reveal that the risks posed by future climate cannot be reasonably mitigated through traditional engineering solutions. Strategies may then need to consider more substantial adaptations such as system realignments, employing nature-based solutions, or strategic facility relocation. The process for making final project decisions will depend on the specific asset, system, and potential consequences of failure.

6.2 Communicating climate risk and uncertainty

As with all climate science data applications, it is important to note potential sources and degrees of uncertainty in projected estimates. Future global greenhouse gas emissions are highly uncertain, given complex trends in population, economic, and technological growth over the coming century. Additional uncertainty is introduced by LOCA2 downscaling methods, limitations in historical records, inherent climate model uncertainties, difficulty capturing regional variability, and potential limitations in representing seasonal or short-term climate variations. These uncertainties result in a wide range of model projections.

It is best practice to utilize the model mean from multiple validated models. Some instances, however, such as project planning for highly critical assets, may require additional analysis to evaluate the impacts of the upper range of the distribution of climate model projections (i.e. mean+2SD).

6.3 Database management

The database and its distribution will be managed by Sonoma Water and Sonoma County Information Systems Department (ISD). ISD will host a subset of these data on their ArcGIS online servers, available to the public. Sonoma Water will evaluate the need for additional variables, such as shorter and longer duration events and temperature variables, to supplement the first version of the database. As users become familiar with the database contents, applications, and limitations, additional variables and revisions can be identified and developed for incorporation into the database. Sonoma Water will also periodically assess the need to incorporate major new climate science developments and datasets to revise or supplement the database such as the next set of IPCC studies, upcoming California Climate Assessments, and the release of NOAA Atlas 15, currently slated for 2027, which will include rainfall scenarios for future climate change.

7. REFERENCES

ESA, 2024. Sonoma Water Future Rainfall Database. Technical methods and results report.

Finzi Hart J, May CL, Mak M, Ramirez-Lopez D, Cohn A, Rockwell J, Anbessie, T. 2022. Climate Projections for Stormwater and Wastewater Resilience Planning.

IPCC, 2021: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change[Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, In press, https://doi.org/10.1017/9781009157896.

Pierce, D. W., D. R. Cayan, E. P. Maurer, J. T. Abatzoglou, and K. C. Hegewisch, 2015: Improved bias correction techniques for hydrological simulations of climate change. Journal of Hydrometeorology, volume 16, page 2421-2442.

Pierce, D. W., D. R. Cayan, D. R. Feldman, and M. D. Risser, 2023: Future Increases in North American Extreme Precipitation in CMIP6 downscaled with LOCA. J. Hydrometeor., https://doi.org/10.1175/JHM-D-22-0194.1, in press.

Sonoma Water, 2020. Flood Management Design Manual.

Sonoma Water, 2021. Climate Adaptation Plan. October, 2021.

Stockhause, M., Matthews, R., Pirani, A., Treguier, A. M., and Yelekci, O.: CMIP6 data documentation and citation in IPCC's Sixth Assessment Report (AR6), EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-2886, https://doi.org/10.5194/egusphere-egu21-2886, 2021